Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Treated wastewater is discharged to the Pacific Ocean via the PLOO at depths of ~94–98 m and at a distance of approximately 7.2 km west of the Point Loma peninsula. The fate of wastewater discharged into offshore waters is determined by oceanographic conditions that impact water mass movement, including horizontal and vertical mixing of the water column and current patterns. These same factors can also affect the distribution of turbidity (or contaminant) plumes that originate from various point and non-point sources. In the Point Loma region these include tidal exchange from San Diego Bay and Mission Bay, outflows from the San Diego River, the Tijuana River and northern San Diego County lagoons and estuaries, storm drains or other water discharges, and surface water runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions either individually or synergistically.

Because of the above, evaluations of oceanographic parameters such as water temperature, salinity, and density that determine the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of these and other parameters (e.g., light transmittance or transmissivity, dissolved oxygen, pH, and chlorophyll) may also elucidate patterns of water mass movement. Monitoring patterns of change in these parameters for the receiving waters surrounding the PLOO can help: (1) describe deviations from expected oceanographic patterns, (2) assess the impact of the wastewater plume relative to other input sources, (3) determine the extent to which water mass movement or mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations.

The evaluation and interpretation of bacterial distribution patterns and remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of wastewater plumes (Pickard and Emery 1990; Svejkovsky 2009; also see Chapter 3 of this report). Thus, the City of San Diego combines measurements of physical oceanographic parameters with assessments of fecal indicator bacteria (FIB) concentrations and remote sensing data to provide further insight into the transport potential in coastal waters surrounding the PLOO discharge site.

This chapter describes the oceanographic conditions that occurred in the Point Loma region during 2008. The results reported herein are also referred to in subsequent chapters to explain patterns of FIB distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern surrounding the PLOO (Figure 2.1). Thirty-six offshore stations (designated F01–F36) were sampled quarterly in January, April, July, and October, usually over a 3-day period. Three of these stations (F01–F03) are located along the 18-m depth contour, while 11 sites are located along each of the following depth contours: 60-m contour (stations F04–F14); 80-m contour (stations F15–F25); 98-m contour (stations F26–F36). Eight additional stations located in the Point Loma kelp bed are subject to the 2001 California Ocean Plan (COP) water contact standards (SWRCB 2001). These

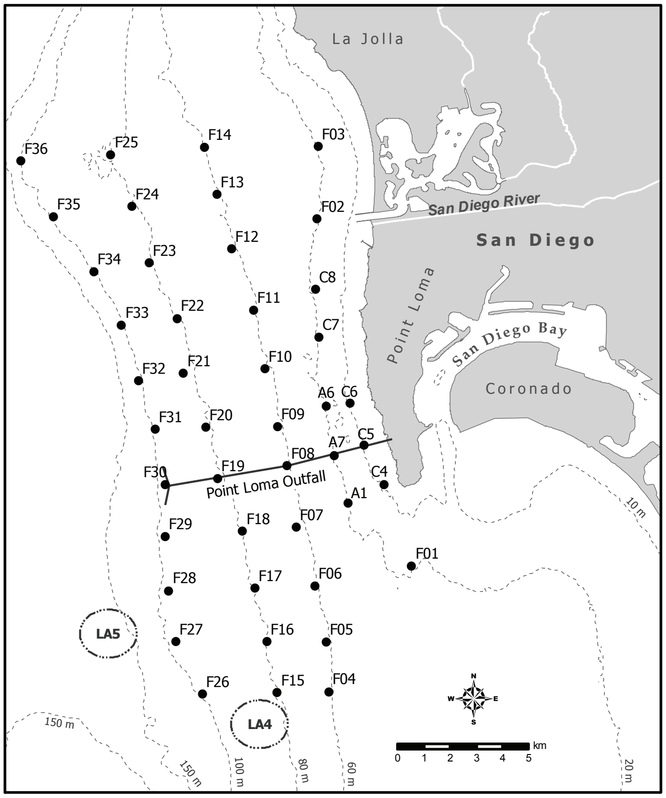

Figure 2.1
Water quality monitoring stations where CTD casts are taken, Point Loma Ocean Outfall Monitoring Program.

stations include three sites (stations C4, C5, C6) located along the inshore edge of the kelp bed paralleling the 9-m depth contour, and five sites (stations A1, A6, A7, C7, C8) located along the 18-m depth contour near the offshore edge of the kelp bed. To meet 2001 COP sampling frequency requirements for kelp forest areas, sampling at the eight kelp bed stations was conducted five times per month.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth (CTD) instrument. The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, water clarity (transmissivity), chlorophyll *a*, and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the PLOO region during 2008 also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, CA (see Svejkovsky 2009). All usable images for the monitoring area captured during the year by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded, and 22 high clarity Landsat Thematic Mapper (TM) images and two Aster images were acquired. High resolution aerial images were collected using Ocean Imaging's DMSC-MKII digital multispectral sensor. The DMSC's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the wastewater discharge signature by differentiating between the waste field and coastal turbidity plumes. Depth of penetration for this sensor varies between 8–15 m depending on water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen DMSC overflights were conducted in 2008, which consisted of one to five flights per month during winter when the surfacing potential was greatest for the wastewater plume (see below) and when rainfall was also greatest. In contrast, only three surveys were flown during the spring and late summer months.

Data Treatment

The water column parameters measured in 2008 were summarized by quarter in two different ways: (1) means calculated over the entire water column for each station, and (2) means calculated over all stations located along each depth contour (i.e., 9-m, 18-m, 60-m, 80-m, 98-m). In order to get a view of the entire PLOO region for each quarterly survey, these analyses included data from all 36 of the offshore stations, as well as the data from the eight kelp bed stations that were sampled at approximately the same time (i.e., ± one day). Each water column parameter was also summarized over all kelp bed stations each month for surface (≤ 2 m) and bottom depths (10–20 m); this was done to identify seasonal trends not necessarily evident in the quarterly data.

Finally, the spatial distributions of temperature and salinity values at each offshore station were mapped for each quarterly survey, with the data limited to the discrete depths at which seawater samples are collected for bacterial analysis.

In addition to the above, mean temperature, salinity, DO, pH, and transmissivity data from 2008 were compared with historical profile plots consisting of means for 1991–2007 ± one standard deviation. Data for these historical analyses were summarized at 5-m depth increments and limited to the three stations located nearest the outfall discharge site along the 98-m depth contour. These included station F30 located immediately offshore of the center of the outfall wye, station F29 located 1.25 km south of the southern diffuser leg, and station F31 located ~1.42 km north of the northern diffuser leg.

Results and Discussion

Climate Factors and Seasonality

Southern California weather can generally be classified into wet (winter) and dry (spring–fall) seasons (NOAA/NWS 2009a), and differences between these seasons affect certain oceanographic conditions (e.g., water column stratification, current patterns and direction). Understanding patterns of change in such conditions is important in that they can affect the transport and distribution of wastewater, storm water, or other types of turbidity plumes that may arise from various point or non-point sources. Winter conditions typically prevail in southern California from December through February during which time higher wind, rain and wave activity often contribute to the formation of a well-mixed or relatively homogenous (non-stratified) water column, and can decrease surface salinity (Jackson 1986). The chance that the wastewater plume from the PLOO may surface is highest during such times when there is little, if any, stratification of the water column. These conditions often extend into March as the frequency of winter storms decreases and the seasons begin to transition from wet to dry. In late March or April the increasing elevation of the sun and lengthening days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In October or November, cooler temperatures associated with seasonal changes in isotherms, reduced solar input, along with increases in stormy weather, begin to cause the return of well-mixed or non-stratified water column conditions.

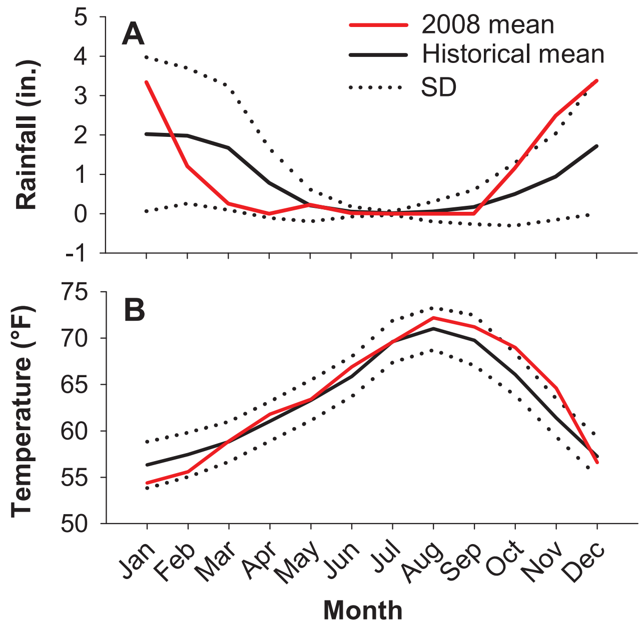

Figure 2.2
Comparison of rainfall (A) and air temperatures (B) at Lindbergh Field (San Diego, CA) for 2008 compared to historical levels. For 2008, rainfall data are expressed as total inches per month, whereas temperature data are monthly averages. Historical rainfall and temperature data are expressed as monthly means ± one standard deviation (SD) for the historical period 1914 through 2007.

Total rainfall in 2008 was just over 12 inches in the San Diego region, which exceeded the historical average (NOAA/NWS 2009b). Rainfall followed expected seasonal storm patterns, with the greatest and most frequent rains occurring during the winter and fall months (Figure 2.2A). Air temperatures were generally similar during the year to historical values, although exceptions occurred in October and November (Figure 2.2B).

Oceanographic Conditions in 2008

Water Temperature

In 2008, mean surface temperatures across the entire PLOO region ranged from 13.4°C in January to 20.9°C in October, while bottom temperatures averaged from 9.5°C in April to 18.5°C in October (Table 2.1). Water temperatures varied as expected by depth and season, with no discernible patterns relative to wastewater discharge (Appendix A.1, Figure 2.3). For example, the lowest temperatures of the year occurred during April at bottom depths along all of the depth contours (Table 2.1), which probably reflected typical spring upwelling in the region. Thermal stratification at stations within the Point Loma kelp forest also followed normal seasonal patterns with the least stratification occurring during the winter months of January, February and December, and the greatest stratification in July–August (Figure 2.4). Although data for the 36 offshore stations off Point Loma are limited to only four times a year, thermal stratification at these stations appeared to follow typical seasonal patterns as well, with the water column ranging from slightly stratified in January to strongly stratified in July and October (see Figure 2.3). Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surface potential of the waste field throughout the year. Moreover, the PLOO wastewater plume was not detected in surface waters at any time during the year based on remote sensing observations (see Svejkovsky 2009) or the results of discrete bacteriological samples (see Chapter 3).

Salinity

Average salinities ranged from a low of 33.21 ppt in January to 33.83 ppt during April in surface waters, and from 33.35 ppt in October to 34.14 ppt in April at bottom depths (Table 2.1). As with temperature, salinity values also appeared to follow expected seasonal patterns. Salinities were highest at bottom depths across the region in April. At the kelp bed stations, salinities also peaked in April and then declined through December (Figure 2.4). These relatively high salinities correspond to the lower temperatures that were found at both surface and bottom depths in April as described above, which is likely indicative of some upwelling in the region during the spring months. Salinity values demonstrated no detectable trends relative to the wastewater discharge site (Appendix A.1, Figure 2.5).

Density

Seawater density is a product of temperature, salinity, and pressure, which in the shallower coastal waters of southern California is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, changes in density typically mirror those in water temperatures. This relationship was true in the Point Loma region during 2008; the differences between surface and bottom water densities resulted in a pycnocline at the offshore stations that was evident in the April, July, and October survey data, with maximum density stratification occurring in July (Appendix A.1).

Dissolved Oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 6.5 to 10.1 mg/L in surface waters and from 2.4 to 7.4 mg/L in bottom waters, while mean pH values ranged from 8.1 to 8.3 in surface waters and from 7.7 to 8.1 in bottom waters across the Point Loma region in 2008 (Table 2.1). Changes in pH patterns were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). For example, concentrations of both parameters peaked during June in surface waters at the kelp bed stations, which corresponded to peak concentrations of chlorophyll *a* indicative of seasonal plankton blooms (Figure 2.4). In contrast, the lowest concentrations of both parameters occurred in bottom waters along all depth contours during April (Table 2.1). These low values near the sea floor during spring may be due to regional upwelling as suggested by temperature and salinity data (see above). Changes in DO and pH levels relative to the wastewater discharge were not discernible (Appendix A.1).

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the PLOO region during 2008. Values are expressed as means for each survey pooled over all stations along each depth contour.

		Jan	Apr	Jul	Oct
Temperature					
9-m	Surface	13.5	14.7	20.4	19.8
	Bottom	13.4	11.1	15.7	18.5
18-m	Surface	13.4	14.3	19.5	19.6
	Bottom	12.9	10.5	12.8	13.8
60-m	Surface	13.6	15.4	19.5	20.2
	Bottom	11.8	9.9	10.9	12.2
80-m	Surface	13.6	15.6	19.3	20.9
	Bottom	11.4	9.7	10.4	11.9
98-m	Surface	13.8	15.4	19.1	20.7
	Bottom	11.0	9.5	10.0	11.5
Salinity					
9-m	Surface	33.37	33.83	33.65	33.37
	Bottom	33.41	33.96	33.71	33.51
18-m	Surface	33.21	33.78	33.63	33.46
	Bottom	33.52	33.94	33.65	33.35
60-m	Surface	33.42	33.65	33.61	33.49
	Bottom	33.68	34.00	33.69	33.39
80-m	Surface	33.44	33.67	33.57	33.52
	Bottom	33.78	34.07	33.78	33.50
98-m	Surface	33.50	33.66	33.52	33.53
	Bottom	33.86	34.14	33.92	33.58
Dissovled Oxygen					
9-m	Surface	7.8	10.1	8.7	6.5
	Bottom	7.4	3.7	6.4	6.8
18-m	Surface	8.1	9.0	8.5	7.7
	Bottom	6.8	3.7	6.7	6.6
60-m	Surface	8.0	8.9	8.4	8.0
	Bottom	4.9	2.7	4.8	6.6
80-m	Surface	8.1	8.9	8.3	7.9
	Bottom	3.7	2.5	4.2	6.1
98-m	Surface	8.1	8.7	8.2	7.8
	Bottom	3.3	2.4	3.6	5.6

		Jan	Apr	Jul	Oct
pH					
9-m	Surface	8.1	8.3	8.2	8.1
	Bottom	8.1	8.0	8.1	8.1
18-m	Surface	8.1	8.2	8.2	8.2
	Bottom	8.0	7.9	8.0	8.0
60-m	Surface	8.2	8.1	8.1	8.3
	Bottom	7.9	7.7	7.8	8.0
80-m	Surface	8.2	8.2	8.1	8.3
	Bottom	7.8	7.7	7.7	8.0
98-m	Surface	8.2	8.1	8.1	8.3
	Bottom	7.8	7.7	7.7	7.9
Transmissivity					
9-m	Surface	76	59	80	85
	Bottom	75	59	81	77
18-m	Surface	76	67	83	86
	Bottom	76	78	81	82
60-m	Surface	82	77	87	86
	Bottom	81	84	87	87
80-m	Surface	84	80	87	86
	Bottom	87	88	87	90
98-m	Surface	86	81	88	87
	Bottom	89	89	89	90
Chlorophyll *a*					
9-m	Surface	1.3	8.7	2.6	1.7
	Bottom	1.6	7.0	2.8	2.9
18-m	Surface	3.7	8.4	3.4	2.0
	Bottom	2.7	7.0	5.7	2.1
60-m	Surface	2.7	4.6	1.3	1.0
	Bottom	1.3	2.4	1.1	1.6
80-m	Surface	2.8	3.1	1.3	1.1
	Bottom	0.6	0.6	0.3	0.7
98-m	Surface	3.1	3.6	1.4	1.0
	Bottom	0.4	0.5	0.2	0.4

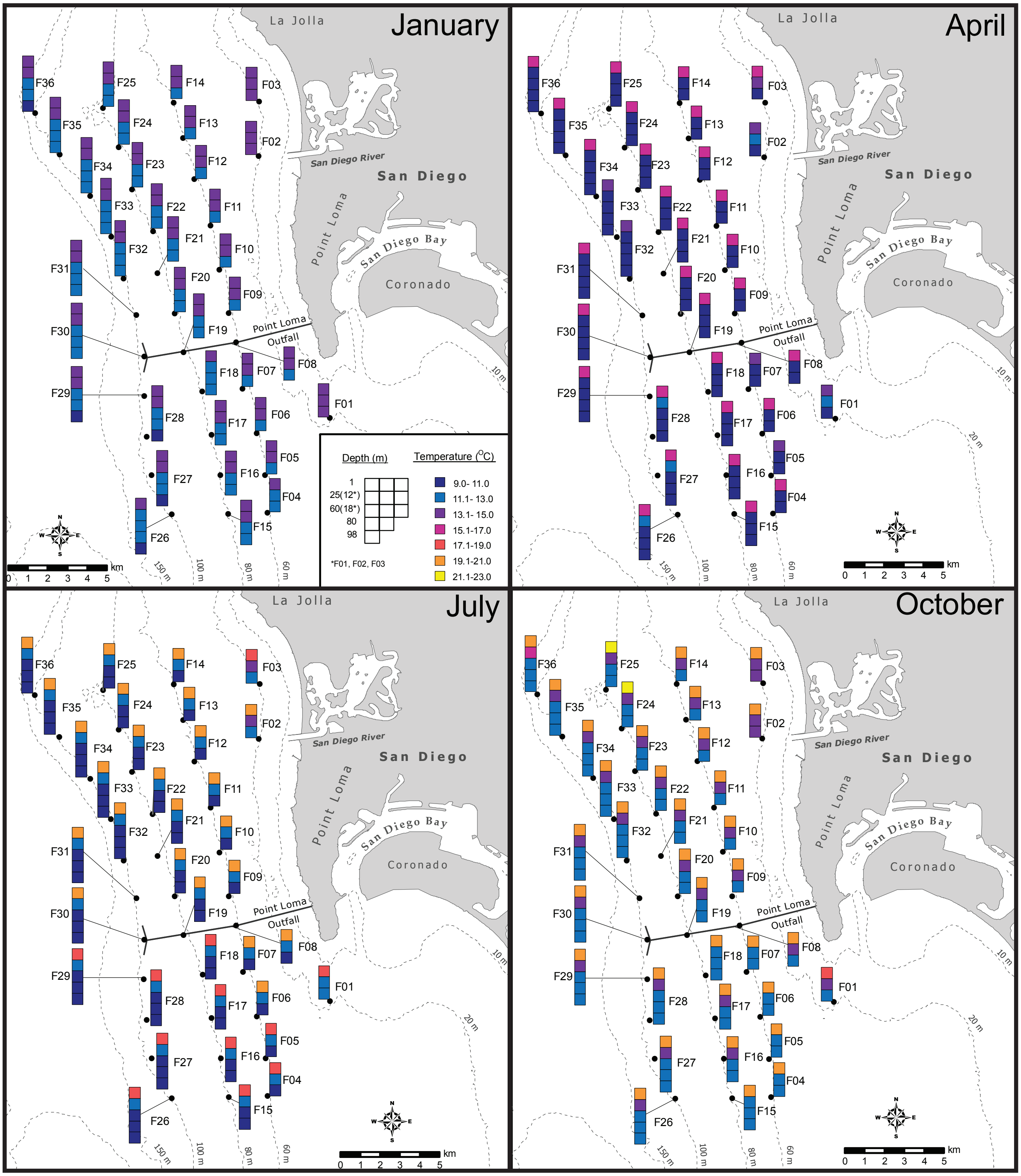

Figure 2.3
Seawater temperatures during quarterly surveys at the offshore PLOO stations in 2008. For each station, data are limited to the discrete depths at which bacterial samples are collected (see Chapter 3).

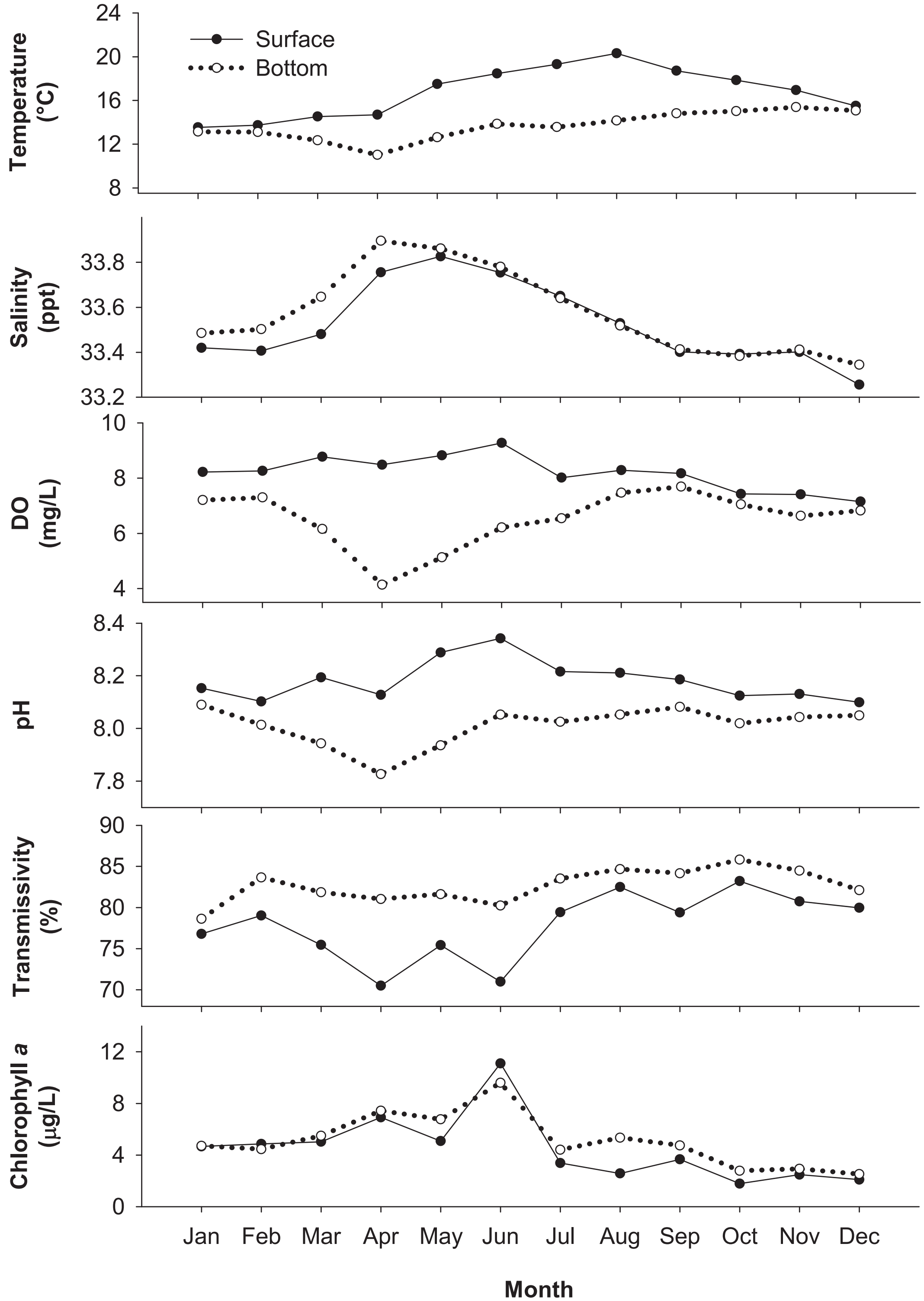

Figure 2.4
Monthly mean temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a*. values for surface (≤2m) and bottom (10–20 m) waters at the Point Loma kelp stations during 2008.

Transmissivity

Transmissivity values were within historical ranges in the PLOO region during 2008 and there were no apparent patterns relative to wastewater discharge (Appendix A.1). For example, transmissivity averaged between about 59 and 90% over all depths during the year (Table 2.1). Additionally, water clarity was consistently greater at the offshore stations when compared to inshore stations by as

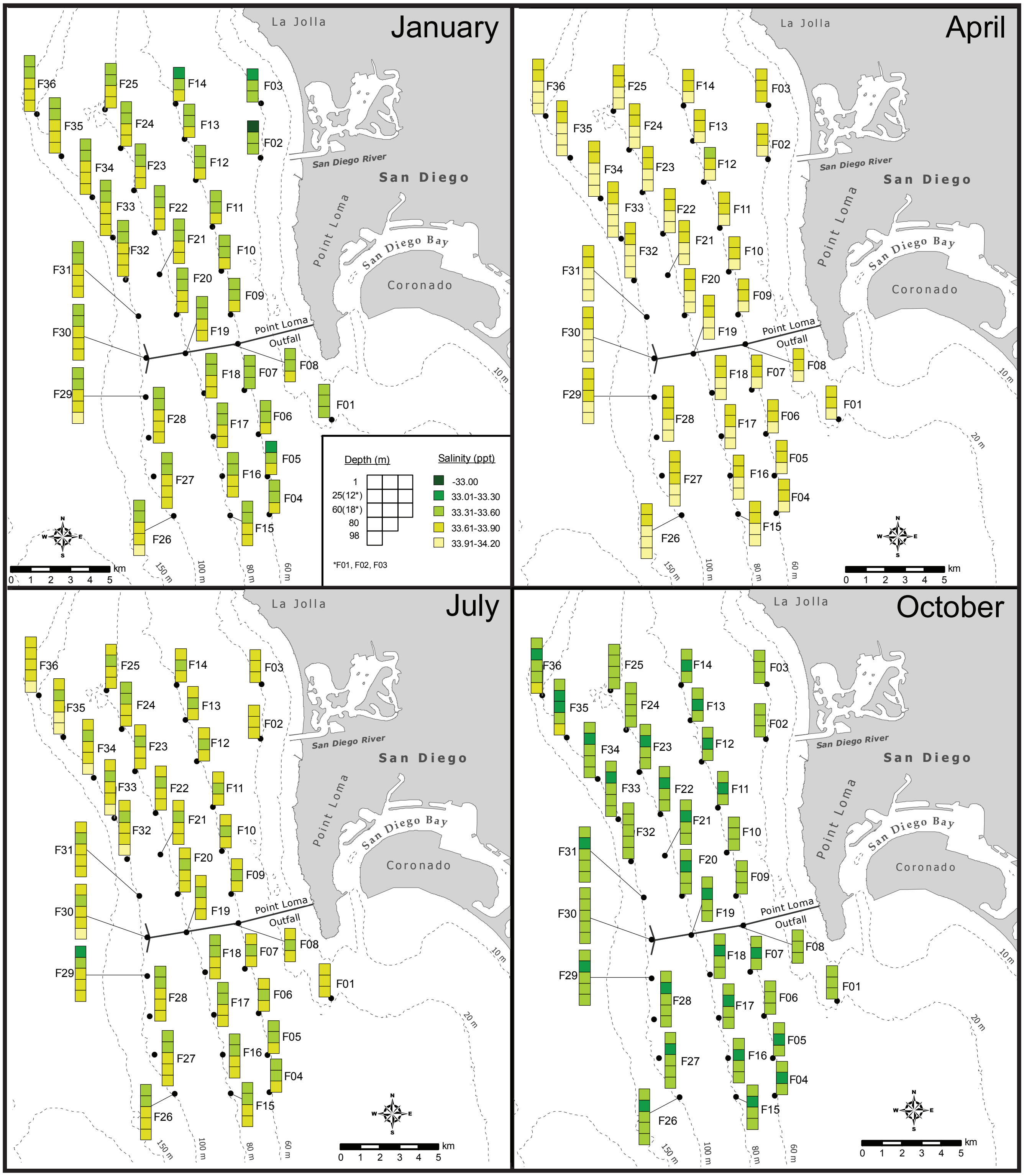

Figure 2.5

Salinity concentrations during quarterly surveys at the offshore PLOO stations in 2008. For each station, data are limited to the discrete depths at which bacterial samples are collected (see Chapter 3).

much as 20% at the surface and 30% at the bottom. Lower transmissivity values in January along the 10-m and 20-m depth contours were likely due to storm and wave activity, while reductions in water clarity in April co-occurred with peaks in chlorophyll *a* values (i.e., phytoplankton blooms). In fact, surface transmissivity values at the kelp bed stations strongly reflect fluctuations in chlorophyll *a* concentrations, which were relatively high in April but peaked in June at these stations (Figure 2.4) (see discussion below).

***Chlorophyll* a**

Mean chlorophyll *a* concentrations ranged from a low of 0.2 µg/L in bottom waters at the offshore sites during July to a high of 8.7 µg/L at inshore surface waters in April (Table 2.1). Chlorophyll concentrations were fairly low at the offshore stations throughout the year. In contrast, monthly averages at the kelp bed stations demonstrate that chlorophyll *a* concentrations were relatively high in this area during April, but were highest in June (Figure 2.4). Such spring blooms are likely related to upwelling events that typically occur during this time of year (Jackson 1986). Unlike past years, no large plankton blooms were visible during the summer months in 2008 (e.g., see Svejkovsky 2009, City of San Diego 2008).

Historical Assessment of Oceanographic Conditions

Water column profiles of temperature, salinity, DO, pH, and transmissivity were analyzed for three nearfield stations (F29, F30, F31) sampled during the January (winter), April (spring), July (summer), and October (fall) quarterly surveys in 2008, after which they were compared to historical profiles for 1991–2007 (Figure 2.6). Water temperatures were fairly typical for the region throughout the year, with values generally within the historical range (i.e., mean ± one standard deviation) during each survey. Only DO exceeded historical conditions during the winter survey, with values well below the historical mean at depths of ≥60 m. During the spring survey, DO was below normal at most depths, while salinity was slightly higher than normal at depths below 60 m. These spring conditions suggest the presence of upwelled water that is typical of this season (Jackson 1986; see also discussion above). Values for most parameters were within historical ranges during the summer. The only exception was transmissivity, which had values above normal at mid-depths (i.e., between 25 and 60 m). In contrast, DO and pH values exceeded the upper end of the historical range at depths around 40 m during the fall survey, while transmissivity dropped below the historical range near 30 m at this time. These unusual conditions during the fall may be due to very strong Santa Ana winds that took place during the first two weeks of October (J. Svejkovsky, personal communication).

Summary and Conclusions

The Point Loma outfall region was characterized by relatively normal oceanographic conditions in 2008, which included localized upwelling and corresponding phytoplankton blooms in the spring. Upwelling events were indicated by cooler than normal water temperatures, especially at bottom depths, and higher than normal salinity in April. The presence of phytoplankton blooms was indicated by increased chlorophyll *a* concentrations during the spring, although these were not supported by remote sensing observations.

There was no apparent relationship between the outfall and values of ocean temperature, salinity, pH, transmissivity, chlorophyll *a*, and dissolved oxygen during 2008. Instead, oceanographic conditions appeared to follow normal seasonal patterns. For example, differences between surface and bottom waters (i.e., stratification) were first evident in the spring, were greatest during the summer, and then declined slightly in the fall. Since temperature is the main contributor to water column stratification in southern California, these differences between surface and bottom waters were important in preventing the waste field from surfacing. The restriction of elevated densities of fecal indicator bacteria to depths of 60 m or below also indicates that the wastewater plume remained

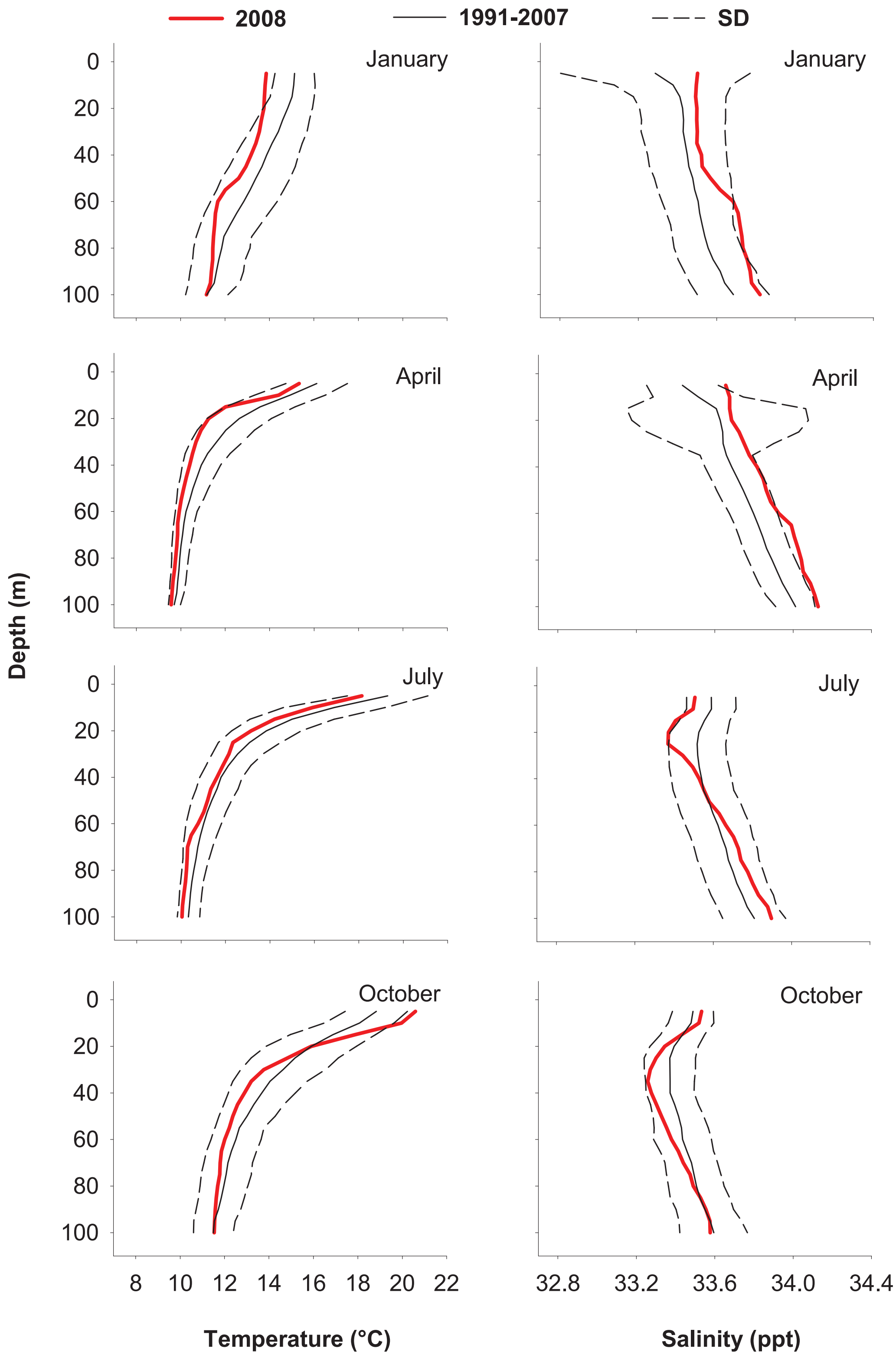

Figure 2.6
Water column temperature, salinity, dissolved oxygen, pH, and transmissivity profiles for 2008 compared to historical data for 1991–2007 at PLOO stations F29, F30, and F31. Data from 2008 are quarterly averages, whereas historical data represent 17-year means ± one standard deviation (SD); both are calculated for each month at 5-m depth intervals.

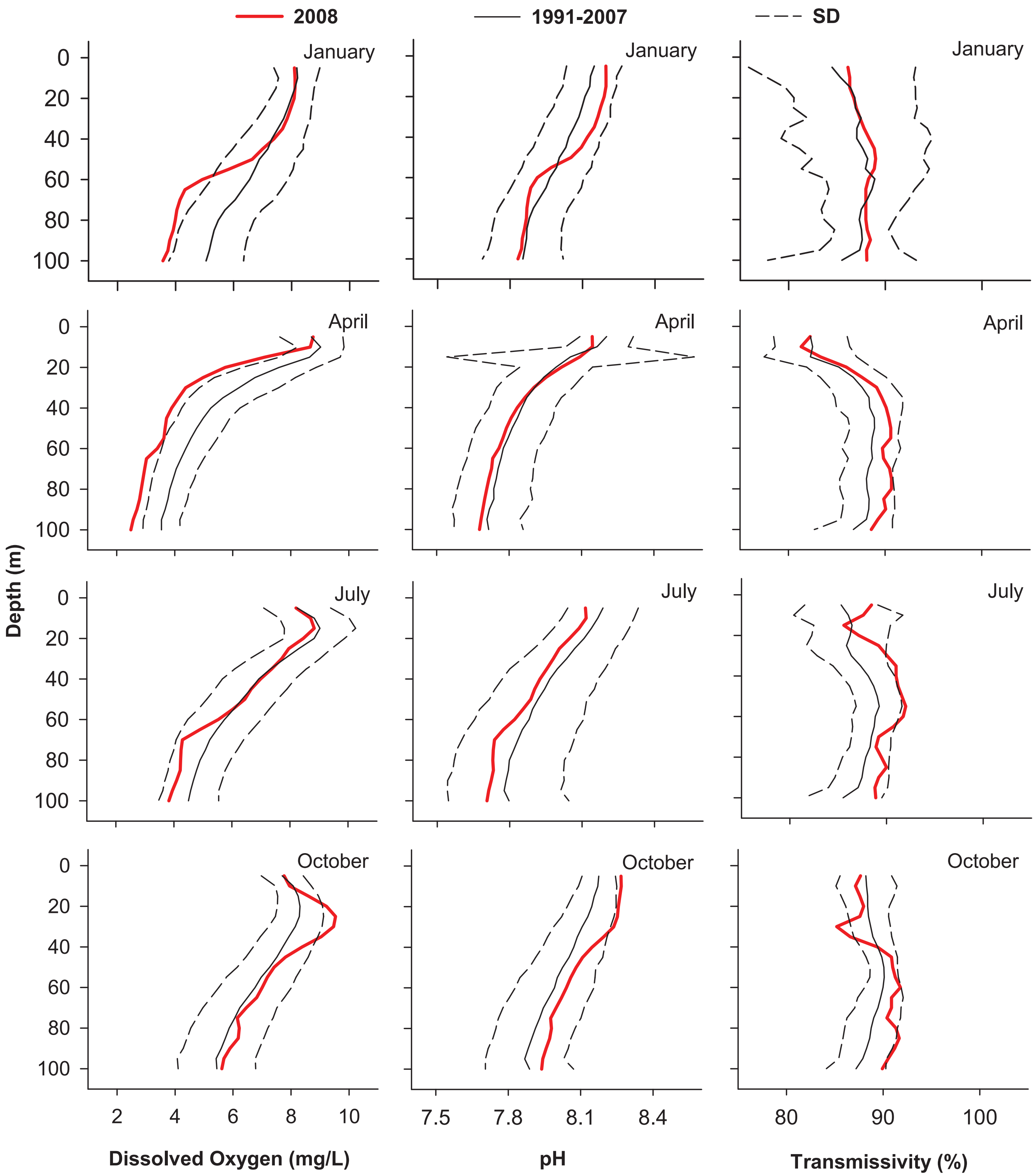

Figure 2.6 *continued*

trapped in relatively deep waters during the year (see Chapter 3). Moreover, the wastewater plume was not detectable in aerial imagery during 2008 (Svejkovsky 2009).

Oceanographic conditions for the SBOO region in 2008 remained notably consistent with long-term analysis of water column data collected between 1991 and 2007, which also did not reveal any changes in oceanographic parameters near the PLOO that could be attributed to wastewater discharge (see City of San Diego 2008). Instead, major changes in water temperatures and salinity off Point Loma region have generally corresponded to significant climate events that occurred within the California Current System (e.g., Peterson et al. 2006; Goericke et al. 2007, McClatchie et al. 2008). Additionally, transmissivity or water clarity has increased in the PLOO region over the past several years, and changes in pH and dissolved oxygen levels have not exhibited any apparent trends related to wastewater discharge.

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